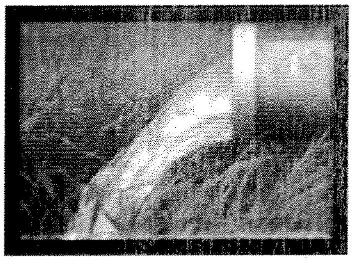


BLAINE T. REELY, PHD, PE

CIVIL ENGINEER - HYDROLOGIST

Tentative Determination of Maximum Annual Yield of Groundwater From Arbuckle – Simpson Groundwater Basin Hearing May 15-16, 2012

EDUCATIONAL SUMMARY

High School – Bullhead City, Arizona (1974)

BSc – University of Arizona (Geological Engineering) (1980)

MSc – University of Arizona (Civil Engineering) Geotechnical / Water Resources (1985)

PhD – Oklahoma State University (Civil Engineering) Water Resources (1992)

MSc Thesis: Strength & Durability of Soil Cement for Flood Control Channel Bank Stabilization

PhD Dissertation: A Linked Simulation – Optimization Groundwater Management Model – Cimarron River Terrace & Alluvial Aquifer

ARIZONA

OKLAHOMA STATE UNIVERSITY

Rancher 3

PROFESSIONAL EXPERIENCE

City of Enid
Enid, Oklahoma – Municipal Public Works

Envirotech Services
OK/AZ/CA – Civil Engineering & Hydrology

Mons[illegible] Consultants
OK/AZ/CA – Civil Engineering & Hydrology

CalPoly University
San Luis Obispo, CA – CIVEN Adjunct Professor

AREA OF DISCUSSION

- Observations & Comments Regarding USGS Scientific Investigations Report 2011-5029
  - Pre-determined goal was stream habitat protection. Different than all other Groundwater Basin Studies in Oklahoma
  - Developed a simplified Modflow groundwater model to simulate recharge – storage – flow – discharge from eastern lobe of the aquifer
  - Used two (2) points of calibration of for the transient model. Blue River gage 07332390 & Pennington Creek gage 07331300
  - Manipulated recharge in model to produce stream discharges that mimic the two calibration points
  - Does not appear that the transient model was calibrated to the potentiometric data for the same calibration period

TRANSIENT MODEL CALIBRATION

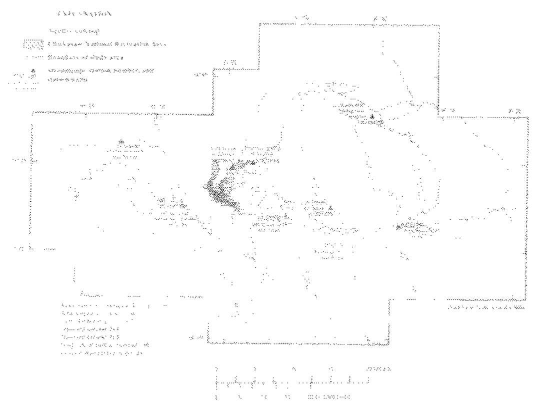


Figure 14. Streamgages located in the study area, south-central Oklahoma

STREAM FLOW ASSESSMENT

Base flow, the flow in a stream channel that represents groundwater discharge and not runoff from storms, was computed for Blue River near Connerville (07332390) and Pennington Creek near Reagan (07331300) by using the PART program (Rutledge, 1998). The PART program scans the streamflow record from a streamgage for days that fit a requirement of antecedent recession, designates base flow to be equal to streamflow on these days, and linearly interpolates the daily record of base flow for days that do not fit the requirement of antecedent recession (Rutledge, 1998). Flow in Blue River near Connerville was computed to be 66 percent base flow and flow in Pennington Creek near Reagan was computed to be 7[illegible] percent base flow for the [illegible]-water-year period from October 1, 2003, to September 30, 2008. Flow in Byrds Mill Spring is only groundwater, with no surface-water components, and, therefore, is 100 percent base flow.

INVESTIGATORS BELIEVE – "BASEFLOW = RECHARGE"

RECHARGE ESTIMATES

The primary method used to determine recharge for the Arbuckle-Simpson aquifer for this study was a recession-curve-displacement method, originally developed by Rorabaugh (1964). That method is based on the measurement of the change in the total potential groundwater discharge (base flow) as estimated at a critical time after the peak by extrapolation from the prepeak and the postpeak recession periods (Rutledge, 1998). Recharge from each precipitation event is assumed to be the difference between the groundwater discharge [illegible] groundwater discharge that would have happened at the same time in the absence of the recharge event, based on extrapolation of the streamflow hydrograph prior to the recharge event. Recharge commonly is divided

Recharge from infiltration of precipitation is difficult to quantify because the recharge rate can vary greatly over short spatial and temporal scales, and is difficult to measure directly. Fairchild and others (1990) estimated an average recharge rate to the Arbuckle-Simpson aquifer of about 4.7 inches per year.

Recharge for every year of data shown in table 9 is greater than the 4.7 inches per year average recharge calculated by Fairchild and others (1990). This difference is thought to be primarily caused by the difference in the surface watershed area for the Blue River near Connerville, Oklahoma, streamgage (162.41 mi²) used by Fairchild and others (1990) and the subsurface watershed area used for this study (88.41 mi²).

Table 9. Quarterly recharge calculated for watersheds upstream from select streamgages on the Arbuckle-Simpson aquifer, south-central Oklahoma.

Station name	Station number	Watershed area (square miles)	Median [illegible] (percent)	Water year	October–December	January–March	April–June	July–September	Yearly total
Blue River near Connerville	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				Average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Honey Creek below Turner Falls near Davis	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				Average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pennington Creek near Reagan	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				Average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

RECHARGE SIMULATION

Recharge

Recharge was simulated by using the MODFLOW recharge package, which simulates areal recharge from infiltration of precipitation through the soil zone. Recharge was only applied at the land surface, which is layer 1 in the eastern Arbuckle-Simpson aquifer MODFLOW model. Recharge was distributed in the eastern Arbuckle-Simpson aquifer model by zones based on the hydrostratigraphic unit at the land surface (fig. 31). Three recharge zones initially were assigned: Arbuckle-Timbered Hills, Simpson, and post-Simpson units (the basement hydrostratigraphic unit was not active in the model and received no recharge). The Arbuckle-Timbered Hills recharge zone was subdivided during [illegible] Arbuckle [illegible] [illegible] Arbuckle-Timbered [illegible] Sulphur fault (see the Model Calibration section of this report).

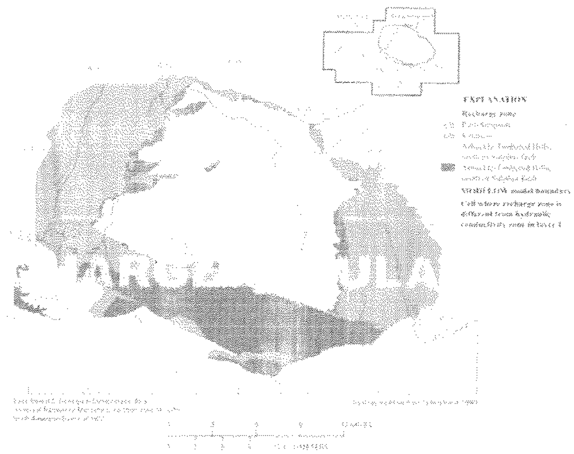
Daily recharge rates calculated by using the RORA program and daily streamflow data from the Blue River near Connerville, Oklahoma, and Pennington Creek near Reagan, Oklahoma, streamgages were initially used for calculating recharge for the MODFLOW model (see the Recharge subsection in the Groundwater section of this report). Modeled daily recharge rates were adjusted from those data during the simulation calibration process (see the Model Calibration section of this report).

RECHARGE – STEADY STATE MODEL

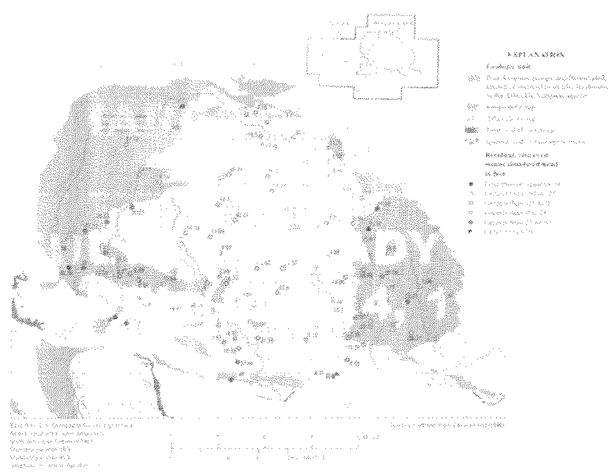
Hills hydrostratigraphic unit. Recharge was initially estimated to be 4.7 inches per year, based on the average estimated by Fairchild and others (1990), where the Arbuckle-Timbered Hills hydrostratigraphic unit was at the land surface, one order of magnitude less for the Simpson and two orders of magnitude less for the post-Simpson. The vertical anisotropy was initially estimated to be 1.0 in all hydrostratigraphic units.

Sulphur fault. Therefore, the recharge zone for the Arbuckle-Timbered Hills zone was divided into two zones separated by the Sulphur fault; recharge north of the Sulphur fault was set [illegible] 8.4 [illegible] 76 [illegible] recharge south of the Sulphur fault was set to 1.82 × 10^{-4} m/d (5.99 × 10^{-4} ft/d [illegible]). Dividing recharge for the Arbuckle-Timbered Hills into two zones improved the match between observed and simulated flows in Blue River and Pennington Creek. After the improvement was noted in the model by assigning different recharge zones north and south of the Sulphur fault, zoning hydraulic conductivity in the Arbuckle-Timbered Hills zone north and south of the Sulphur fault was tried, but no improvement was observed in the distribution of simulated heads and flows from that zoning.

RECHARGE SIMULATION



RESULTS – STEADY STATE MODEL (Aug 14, 1995)



RESULTS – STEADY STATE MODEL (Aug 14, 1995)

A groundwater-model volumetric budget, commonly referred to as a "water budget," is a tabulation of groundwater flow into or out of the simulated aquifer. The water budget for the eastern Arbuckle-Simpson aquifer under steady-state conditions is 158.11 ft³/s of recharge and 158.11 ft³/s of discharge to drains. Simulated streamflow for the steady-state model of 152.45 ft³/s is shown in table 18; the difference, 5.66 ft³/s, is the difference between simulated streamflow as discharge to drains for the entire model and simulated streamflow for streams with observed streamflow.

Table 18. Simulated streamflows compared to streamflow measurements on August 14, 1995.

Stream observation	Observed streamflow (ft³/s)	Simulated streamflow (ft³/s)
Blue River	[illegible]	73.57
Buckhorn Creek	3.24	2.87
Byrds Mill Spring	[illegible]	14.84
Delaware Creek	1.93	5.05
Mill Creek	[illegible]	6.03
Pennington Creek	[illegible]	29.03
Rock Creek	[illegible]	18.19
Sheep Creek	[illegible]	6.01
Total	[illegible]	152.45

RECHARGE – TRANSIENT MODEL

Recharge computed by the RORA program is based on streamflow-gaging data and the area of the subsurface watershed upstream from the stream gage. The recharge rate was applied to MODFLOW recharge zones (fig. 31) that are based on the hydrostratigraphic unit at the land surface, and recharge to the Simpson and post-Simpson hydrostratigraphic units were computed as a fraction of the recharge rate to the Arbuckle-Timbered Hills hydrostratigraphic unit north of the Sulphur fault. Area-weighted annual recharge rates applied to the model domain averaged 5.58 inches (142 millimeters (mm)) per year for water years 2004–8, and ranged from 2.17 inches (65.3 mm) in water year 2006 to 11.61 inches (295 mm) in water year 2007 (table 19). The area-weighted applied rates are lower than the recharge rates computed [illegible] because the recharge rates are lower for areas overlain by the Simpson and post-Simpson hydrostratigraphic units.

Table 19. Area-weighted average annual recharge for the eastern Arbuckle-Simpson aquifer, south-central Oklahoma, MODFLOW model for water years 2004–8.

	Water year					
	2004	2005	2006	2007	2008	5-year average
Recharge (inches)	6.26	7.52	[illegible]	11.61	[illegible]	5.58

STREAM CALIBRATION – TRANSIENT MODEL

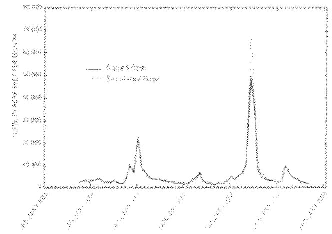


Figure 36. Monthly gaged streamflow compared to monthly simulated streamflow (MODFLOW-simulated groundwater discharge plus PART-computed runoff) for Blue River near Connerville, Oklahoma, for water years 2004–8

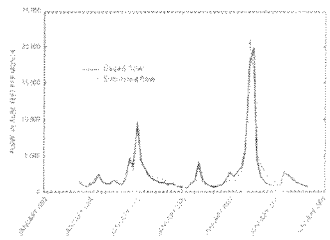


Figure 37. Monthly gaged streamflow compared to monthly simulated streamflow (MODFLOW-simulated groundwater discharge plus PART-computed runoff) for Pennington Creek near Reagan, Oklahoma, for water years 2004–8

Although the transient model calibration was primarily based on streamflows in Blue River and Pennington Creek, the model also reproduces head response in observation wells. Comparison between observed average daily head and simulated median monthly heads in observation wells is shown in figure 38. Daily head observations were compared to simulated median monthly head because the eastern Arbuckle-Simpson MODFLOW model does not simulate the

[illegible] therefore, recharge in the model arrives at the water table instantaneously, which causes a short-term, unrealistic increase in simulated head. The actual recharge in the aquifer is delayed and takes some finite period of time as the recharge moves through the unsaturated zone. Simulated head responses tend to reproduce the general character but do not exactly match observed head responses. The study objectives emphasize modeling streamflow, not heads, so that the differences between observed and simulated water levels were considered to be acceptable

WELL CALIBRATION – TRANSIENT MODEL

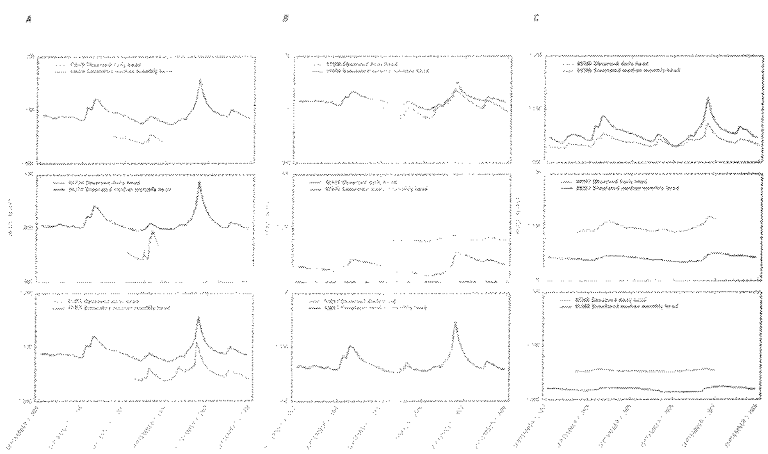


Figure 38. Comparison of observed and simulated heads for wells equipped with [illegible] water levels continuously in the eastern Arbuckle-Simpson aquifer, south-central Oklahoma, for water years 2004–8

WELL CALIBRATION – TRANSIENT MODEL

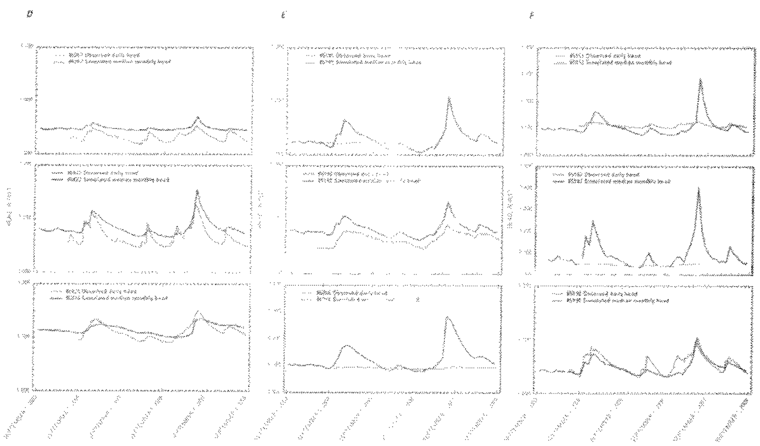


Figure 38. Comparison of observed and simulated heads for wells equipped with instruments to measure water levels continuously in the eastern Arbuckle-Simpson aquifer, south-central Oklahoma, for water years 2004-8.—Continued

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

- **PRIOR RIGHTS**
  - **11 Permits**
  - **5696 Ac-Ft**
- **Temporary Permits**
  - **48 Permits**
  - **74,524 Ac-Ft**
  - **45,419.9 Ac**
- **Pending Permits**
  - **13 Permits**
  - **109,901.6 Ac-Ft**
  - **57,128.4 AC**

AREA OF DISCUSSION

- Phased Implementation of Maximum Annual Yield
  - Under recommendations, Maximum Annual Yield = 78,404 Ac-Ft
  - Existing Allocations (Prior and Temporary Rights) = 80,220.3 Ac-Ft
  - Current "Over Allocation" = 1816.3 Ac-Ft
- If all existing temporary permits are immediately converted to 0.2 Ac-Ft / Acre then (45,419.9 Ac X 0.2) = 9083.98 Ac-Ft
  - Available Additional Allocation = 63,624.02 Ac-Ft
- If all existing pending permit applications are awarded at 0.2 Ac-Ft / Acre then (57128.4 X 0.2) = 11,425.68 Ac- Ft
  - Available Additional Allocation = 52,198.34 Ac-Ft